
Evaluation of Hot Carrier Induced Degradation of MOSFET Devices

Application Note 4156-3

**HP 4155A/4156A
Semiconductor Parameter
Analyzer**



Introduction

With device feature size scaling down, hot carrier induced degradation has become a serious problem. Due to the hot carrier injection into the gate oxide, threshold voltage (V_{th}) and transconductance (G_m) of the device can shift substantially. Depending upon the degree of the V_{th} and G_m shift, the speed of device will degrade and finally the device will not function. The evaluation of hot carrier induced degradation is currently important for the development of reliable ULSI technologies. This application note shows how to evaluate hot carrier induced degradation using the HP 4155A/4156A semiconductor parameter analyzer.

What is hot carrier induced degradation

Devices used in today's ULSI technologies have very short channel lengths (in the sub-half micron range), which increases the electric field of the channel. The drain current easily ionizes electrons and holes around the drain (impact ionization), which causes hot electron and hot hole injection into the gate oxide (Drain Avalanche Hot Carrier: DAHC).

Some of the hot carriers are captured in the deep gate bias region, so the device's threshold voltage (V_{th}) and transconductance (G_m) are shifted.

Problems in evaluation of hot carrier life

To evaluate the hot carrier induced degradation of a MOSFET, the test flow shown in Figure 2 is performed and the resulting hot carrier life is estimated. Before executing the test, stress voltage conditions should be defined appropriately so that they create the greatest rate of degradation of the MOSFET. I_{sub} - V_g characteristics are measured to define the gate stress voltage.

The test repeatedly applies a voltage stress condition and measures the parameters, such as V_{th} and G_m . At the end of the test, a graph of the measured parameter shift versus stress time is drawn and hot carrier life is estimated.

Total test time is very long in general. So it is necessary to fully automate testing. But programming to control measurement instruments and to extract parameters is complicated. Also programming to draw the graph of parameter shift versus stress time and to estimate hot carrier life is tedious. The long test time requires a controller, which increases the total test cost.

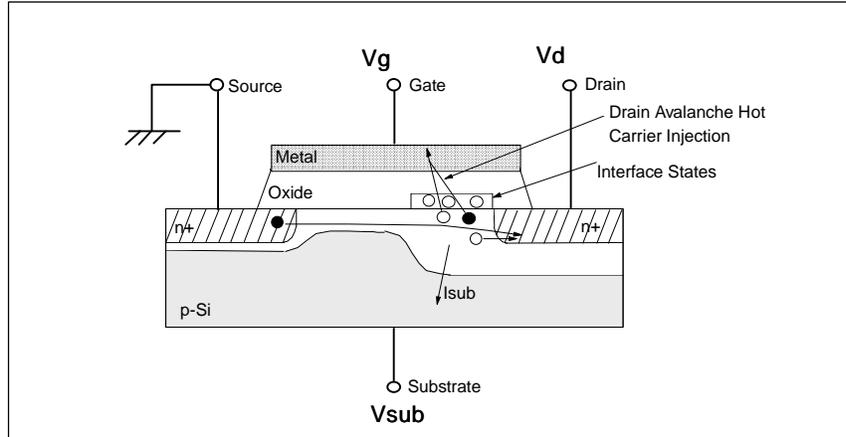


Figure 1. Drain Avalanche Hot Carrier

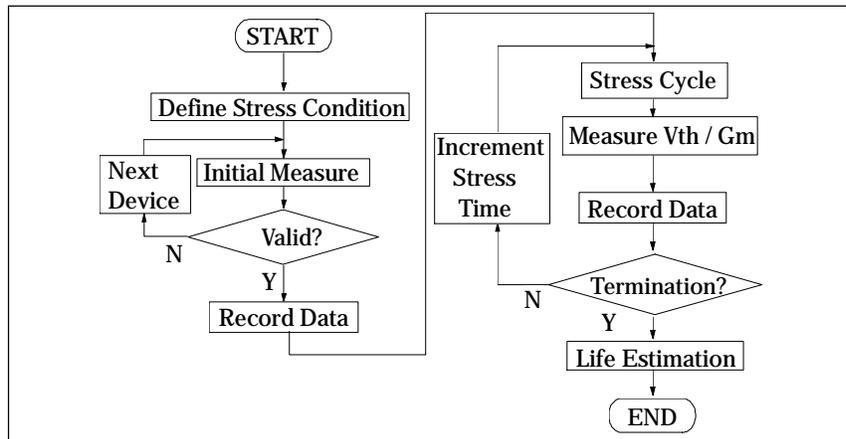


Figure 2. Flowchart of Evaluating Hot Carrier Induced Degradation

Hot carrier life estimation using the HP 4155A/4156A

The HP 4155A/4156A includes HP Instrument BASIC internally. HP Instrument BASIC is a subset of the well known HP BASIC optimized for instrument control and scientific calculation. The entire test can be controlled and automated with a small HP Instrument BASIC program. No external controller is necessary.

The stress and measurement cycle test is done by loading previously saved measurement/stress setup files. You set stress and measurement conditions by editing fill-in-the-blank screens, then saving them as a setup file. This greatly simplifies test programming. Using HP Instrument BASIC, the HP 4155A/4156A can draw graphs of

the data arrays, such as shift V_{th} versus stress time. Complicated programming to draw graphs and to calculate data is not necessary.

Defining the stress conditions

To generate maximum hot carriers, the appropriate gate and drain voltages need to be determined in advance as part of the stress condition. The stress condition should be defined as follows:

Drain stress voltage (V_{dstr}):

0.5 V below actual breakdown is recommended

Gate stress voltage (V_{gstr}):

The substrate current (I_{sub}) is measured while gate voltage (V_g) is swept with the drain voltage set to V_{dstr} . V_{gstr} is defined as the gate voltage where I_{sub} is the maximum on the I_{sub} - V_g curve.

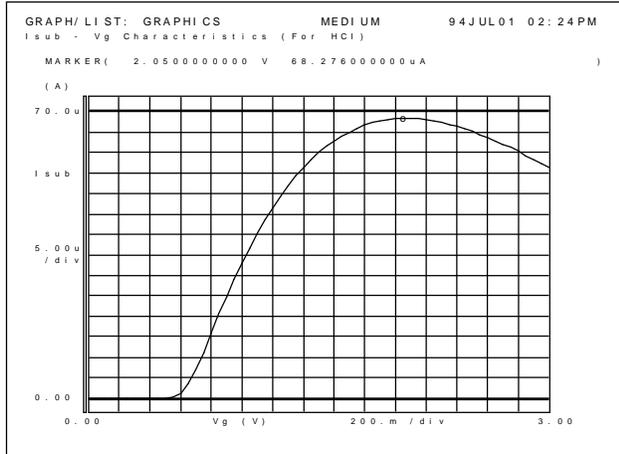


Figure 3. Isub - Vg Curve To Define Gate Stress Voltage

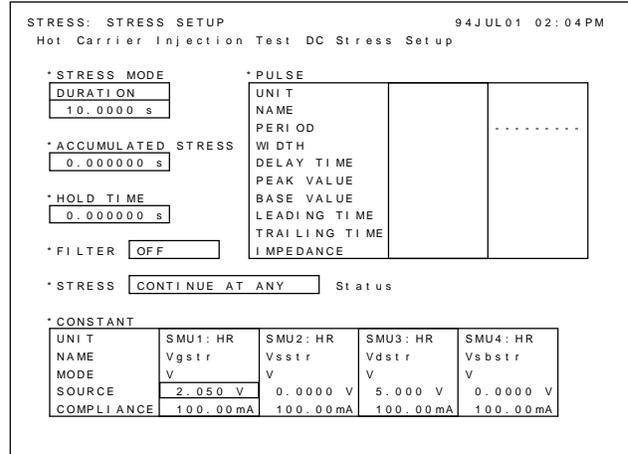


Figure 4. Stress Setup Page

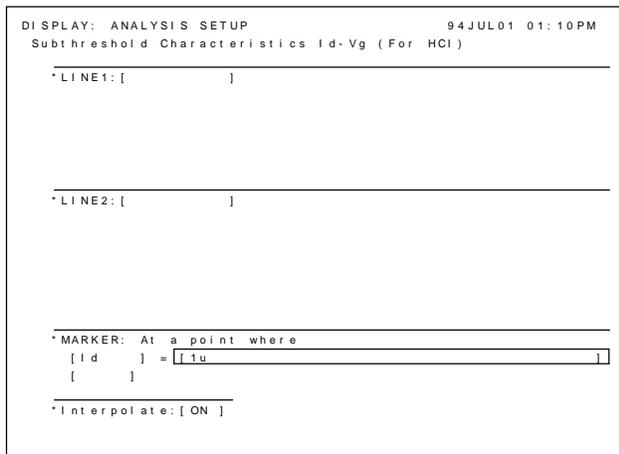


Figure 5. Auto Analysis Setup Page

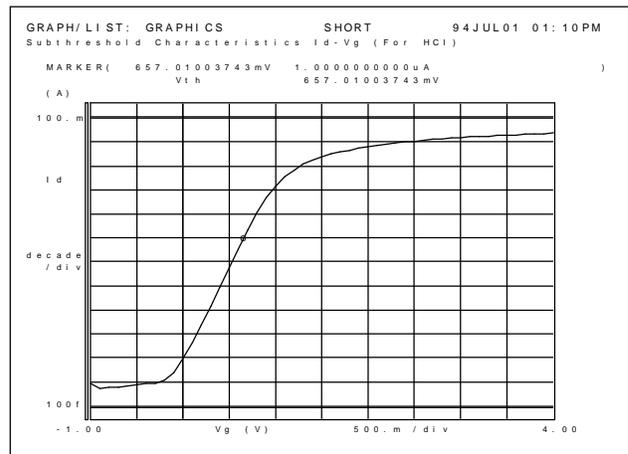


Figure 6. Vth Measurement Result

An example Isub - Vg curve is shown in figure 3. In this example, Vgstr is determined to be 2.050 V.

Applying the DC stress

"Stress mode" is a new feature introduced in the HP 4155A/56A which greatly simplifies defining stress-measure conditions. Stress voltages and/or currents can be pre-defined and called from memory quickly, and separately from the measurement test conditions.

In this mode, the stress time is controlled accurately. To setup the stress condition, you just need to specify the value of stress voltages in fill-in-the-blank manner and save the condition into a stress setup file. As your device design requirements change, you only need to modify and save the new stress setup file.

Figure 4 shows an example stress setup. Vdstr and Vgstr are 5.000 V and 2.050 V respectively.

The stress time is incremented logarithmically with each stress-measure cycle. Measurements in this example are made after 10, 20, 50, 100, 200 1,000,000 seconds of cumulative stress time. The stress-measure cycles are repeated until a target degradation is reached or until the target accumulated stress time is reached. Those tasks are fully automated by HP Instrument BASIC.

How to measure Vth

Another new feature of the HP 4155/4156A is the sweep measurement "auto analysis" function. This powerful built-in

function automates extraction of parameters, such as Vth and maximum Gm. The auto analysis setup is simplified with fill-in-the-blank prompts.

There are several methods for making Vth measurements, such as extrapolated Vth and constant current Vth. Figure 5 shows an example analysis setup of constant current Vth. The drain current Id is measured while Vg is swept with constant drain voltage. In this example, the Vth is defined as the gate voltage where the Id is equal to 1 μ A. In general, the target constant drain current (Id) is defined as

$$I_d = 1 \mu\text{A} \times W / L$$

where W is channel width and L is channel length of the nMOSFET.

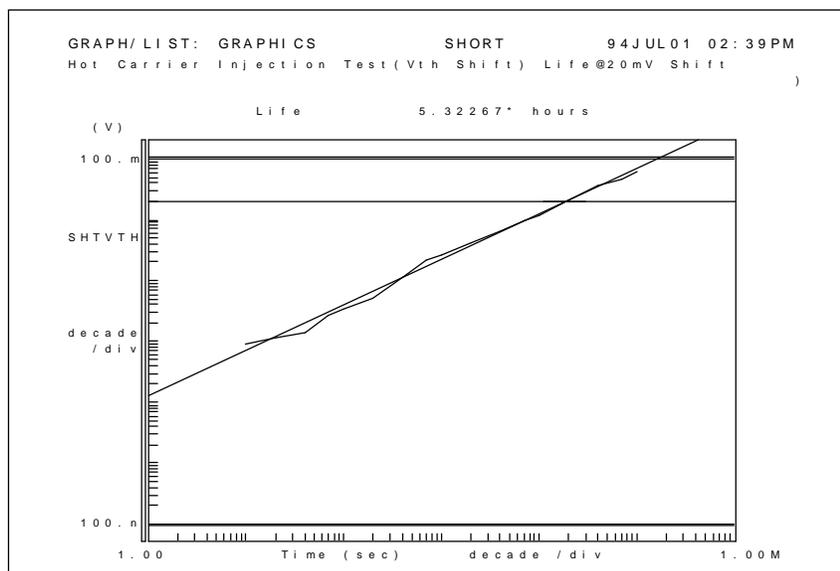


Figure 7. Estimation of Hot Carrier Life

Figure 5 is an example of auto analysis setup, and Figure 6 is an example of V_{th} measurement result. In this example, V_{th} is 0.657 V. Both extracted V_{th} data and cumulated stress time data are stored into data arrays of the HP Instrument BASIC program.

Estimation of hot carrier life

The stored data arrays from HP Instrument BASIC program can be transferred to HP 4155A/4156A's graphics data. As the device degradation follows a power law with stress time, V_{th} shift from initial V_{th} versus stress time is plotted on a log-log graph.

Using the new regression line function, a least-square fit line is added to the plot. The hot carrier life is defined as the stress time at which V_{th} has shifted by 20 mV from its initial V_{th} . The life can be estimated by interpolation or extrapolation from the least-square fit. From our experience, in the case of the extrapolated V_{th} measurement, the least-square fit line is not correct in the shorter stress time range. Because at first V_{th} decreases, so the shift of V_{th} goes negative. This is due to the changes of the I_d - V_g slope.

In above example, the hot carrier life is estimated as 19,162 sec (= 5.32 hours).

Conclusion

The HP 4155A/4156A simplifies your evaluation of hot carrier induced degradation. No external controller is necessary. A sample software disk furnished with the HP 4155A/4156A gets you up and testing right away.

This application note describes an example of the hot carrier life estimation using the constant current V_{th} shift method. It is also easy to estimate hot carrier life from extrapolated V_{th} , G_m or linear drain current shift.

You may also apply AC stress or charge pumping techniques using the optional pulse generator units (PGU) and PGU/SMU selector. You can apply stress voltages to multiple devices at same time by using a switching matrix, which can be controlled by HP Instrument BASIC through HP-IB port of the HP 4155A/4156A.

Reference:

Proposed JEDEC Hot Carrier Stress Specification, Sep. 7, 1993

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